Fermi National Accelerator Laboratory

FERMILAB-FN-625
DO Note 2250

C-Tagging of Jets from W Decays

Ryuji Yamada

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

October 1994

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

Disclaimer

C-Tagging of Jets from W decays

Ryuji Yamada

September 14, 1994

I. Introduction

In the study of mass analysis for t-tbar events, the information of soft lepton tagging of jets is utilized, to designate a jet as a b-jet. The jets of top candidates in the lepton-jets and all-jets channels may have soft muons tagged. Many of these muons may be coming from b-jets and their cascade c-jets, which are regarded as a part of b-tagging. But there is a probability that some of the muon tagged jet is the c-jet, which is one of two jets decaying from a real W. We want to make a rough estimation for the probability of c-tagging for the selected-out top candidate events, using branching ratios available in the Review of Particle Properties. C-tagging should be considered when assigning jets for the mass analysis of top candidates. For the calculation of the top cross section this c-tagging for soft lepton tagged channels should be considered.

The detection efficiency is not considered in this report, but it could be applied uniformly for all of cases, which is in the order of 50 %. If we are discussing and allocating tagging mechanism for the existing top candidates, the ratios are same. We need Monte Carlo calculation for further analysis, considering efficiencies and all cuts in the experimental data. The probability of muon tagging from the K decays is also estimated. In the following discussion, we handle mainly muons, but the same discussion applies to electrons.

II. Top Decay Modes

There are two tops in one t-tbar event. Each top decays into a b-quark and a W. In the all-jets mode, both tops, and both W's decay in the following way,

```
t -----> b + W
             l l
             l l----------> u + dbar,      50 % chance      (1)
             l-----------> c + sbar.       50 % chance.     (2)
```

In the lepton-jets mode, one of two tops decays as described above, but the other remaining top decays into a b-quark, a high pt lepton and a neutrino as follows,

```
t -----> b + W
              l
              l----------> high pt lepton + ν.              (3)
```

Typically the lepton-jets top candidates have four jets, and the all-jets top candidates have six jets.

If the mass of the top is 174 GeV and if it is made at rest, the energy of the b-quark is 68.6 GeV, and the energy of the W is 105.4 GeV.

III. W Decay Modes

The branching ratios of W decays into e-ν, μ-ν, τ-ν, a jet pair of u-dbar, and a jet pair of c-sbar, are 1/9, 1/9, 1/9, 3/9, and 3/9 respectively, neglecting mass effects.

```
                                  Branching  Ratio
W      ---->  e  +  ν               1/9
       ---->  μ  +  ν               1/9
       ---->  τ  +  ν               1/9

       ---->  u  +  dbar            3/9                            (4)
       ---->  c  +  sbar            3/9                            (5)
              lll     l
              lll     l-------> K + X                              (6)
              lll--------------> K + X                             (7)
              ll
              ll-------> s (jet) + soft μ + ν + X      semileptonic (8)
              l--------> s (jet) + soft e + ν + X.     semileptonic (9)
```

In this report we are mainly concerned with the last two W decay modes into two jets (4) and (5). The decay mode into the c-sbar has the possibility that the c quark decays further semileptonically and generates a soft muon or a soft electron together with a jet (8) or (9).

The c quark and sbar quark decay into jets, generating K mesons. The K mesons have possibility to decay with soft muons, and their probability is considered later.

IV. Decay Mode of c-quark from W

The energy of c-quark is approximately a half of the energy of W, roughly 53 GeV. We assume the c-quark does not go through an extensive fragmentation process. The c-quark will hadronize into D^{+-}, D^0 and D_s^{+-} mesons and their excited states. They will decay in the semileptonic decay mode and generate muons. Their major decay modes with soft muons are listed in Appendix I with their branching ratios. Mostly they are three body decay modes, and we roughly estimate the energy of the soft lepton is about one third of 53 GeV; namely 18 GeV. Therefore the decaying muon can be a fairly energetic one, with a moderate pt value, and should be easily detected. For the c-jet within eta less than 2.0, we just assume its decay probability with a soft lepton is 10 %. Its pt spectrum should be obtained by a Monte Carlo calculation.

V. Decay Mode of b-quarks and their daughter c-quarks

We assume a b-quark decays as follow,

```
b -----> c + μ + ν              10 %    Semilept.          1 moderate pt μ   (10)
l        l
l        l----> s + μ + ν        1 %    Cascade            1 moderate pt μ
l                                                           + 1 soft pt μ     (11)
l -----> c + X                 (90 %)   Remainder                            (12)
         l
         l---->  μ + anything    9 %    Lept. & Semilept   1 soft pt μ       (13)
```

The probability of soft muon b-tagging for the lepton-jets channel was studied, and reported by D0 and CDF groups. 1), 2) It is about 20 % per b-jet, including the contribution from its c-decay, without detection efficiency included. We define the soft lepton b-tagged jet as the b-jet with a soft lepton or two. These leptons are from b-decay (10) or from its daughter's c-decay (13). The semileptonic decay probability of b-quark with a lepton (a muon or an electron): b --> c + lepton + neutrino (10), alone is assumed 10 %. The b-quarks hadronize into B^{+-} and B^0 mesons and their excited states. Their major decay modes and other related modes are listed in Appendix II.

If we assume the mass of a top quark is 174 GeV, the average energy of the b-quark is more than 69 GeV. We assume the b-quark does not go through an extensive fragmentation process. In the three body decay of semileptonic decay mode, we assume the average energies of the generated particles, a c-quark, a lepton and a neutrino, are about 23 GeV. The resulting muon will have a moderately high pt. The energies of the lepton and neutrino, are still substantial amount and need a careful energy correction for top mass analysis.

Practically all of other b-quarks decay into charmed D mesons and their excited states (12). The average energy of the daughter c-quarks may be about 23 GeV. These particles, containing c-quarks, decay subsequently and generate leptons, and we assume its probability is 9 % (=90% x10%) (13). We assume these decays are mostly three or four body decays, and the emerging leptons will have energies about 8 GeV. We expect these muons are detected with a reasonable efficiency, because the minimum energy for a muon to go through the D0 toroids is about 3.5 ~ 4.0 GeV.

The resulting D mesons will decay with K mesons with overall decay ratio of about 25%. The effect of K mesons is considered later.

VI. Lepton-Jets Channel

In one t-tbar event, decaying into the lepton-jets channel, there are one high pt lepton, a neutrino, two b quarks and two more jets. These two jets come from a decay of a W, and there is a 50 % probability that these two jets are a c-sbar pair. Then there is probability that one of two jets from the W decay has a muon form c quark decay. The probability of c-tagging for each selected out t-tbar lepton-jets event, is 50 % x 10 % = 5 %.

For each t-tbar lepton-jets event, there is two b-quarks. There is 30.8 % (=2x19(1.00-0.19) %) probability of having one-b-tagging, and 3.6 % (=19% x19%) probability of having b-tagging in both b-jets. Likewise the probability of having simultaneously a b-tagging and a c-tagging from W for a t-tbar event is 1.5 % (=30.8% x5%). The chance of having two muons in one b-jet due to the cascade b and c decay is 2 % (=2 x1%).

We do not have a clear-cut experimental mechanism to distinguish a soft muon of c-tagging from a soft muon of b-tagging. This means if we have a one- or two-tagged lepton-jets event, the chance of that event being a one-b-tagged event is 71.8 % (=30.8/42.9) out of all tagged events. The chance of seeing the event of two-b-tagging is 8.4 %. The chance of seeing the event of c-tagging is 11.7 %. Also the chance of seeing the event of simultaneous b-tagging and c-tagging is about 3.5 %. The total chance to see a c-tagging is 15.2 %. These probabilities are summarized in Table I.

Table I. Ratios of c-tagging and b-tagging for lepton-jets and all-jets events.

The percentage (probability) in the first rows of each channel corresponds to all events in that channel with and without soft muon tagging. The percentage in the second rows (chance) correspond to the chance for only tagged event in that channel.

Tagging	one-b (%)	two-b (both b's) (%)	two-b (in one b) (%)	one-c (%)	b&c (%)	total (%)
Lepton-Jets						
for all (probability)	30.8	3.6	2	5	1.5	42.9
for tagged only (chance)	71.8	8.4	4.7	11.7	3.5	100.1
All-Jets						
for all (probability)	30.8	3.6	2	10	3.1	49.5
for tagged only (chance)	62.2	7.3	4.0	20.2	6.3	100

VII. All-jets Channel

In an all-jets t-tbar event, both W's decay into two jets. There are two b-quark jets, and there is one c-quark jet on the average. If we assume b- and c- quarks decay with muons at the rates of 19 and 10 % respectively, there are 30.8 % probability to have one-b-tagged event, and

10% probability of c-tagged event. The probability of having a b-tagging and a c-tagging in a same event is 6.3 %.

When we have a tagged all-jets event, the chance of having a b-tagged event out of all possible tagged all-jets event is 62.2 %. The corresponding value for a c-tagged event is 20.2 %. That of having simultaneous b-tagging and c-tagging is 6.3 %, and that of having two b-tagging is 7.3 %. The summary of this channel is also given in Table I. The total chance to have a c-tagging is 26.5 %.

VIII. Probability of K tagging

With the D0 detector, if we do not use the information in the vertex and TRD detectors, and if the K mesons decay with muons within the inside radius (50 cm) of the CDC, these muons may be indistinguishable from the muons originating from the b- and c-tagging. If the kink due to the K decay is big enough, the emerging muon will be isolated from the jet.

1. K from sbar-quark

The sbar quark in (5), which is generated from the W decay, hadronizes into charged and neutral K mesons and their excited states. Their major decay modes with muons are listed in Appendix III. These decays are two or three body decays. If the energy of the sbar jet is above 53 GeV, the energy of the muons may be about 18 GeV on the average. We just assume these decay muons are accompanied with jets with pt higher than 15 GeV in the central eta area.

We assume the energy of the generated charged K mesons is 20 (~ 53) GeV, and their decay length is 150 m. The probability of a sbar-jet decaying with a muon in the radius 0.5 m, is (0.5m/150m) x 0.5(only charged K) = 0.17 %. And there is only 0.5 sbar-jet per event. Therefore the contribution from the K mesons directly from the sbar quark may be negligible for the muon tagging.

2. K from b-quark chain

The b-quarks hadronize into B^{+-} and B^0 mesons and their excited states. And the B^{+-} mesons decay into K^{+-} anything mode with 85% branching ratio, and into K^0/K^0bar anything mode with 63% branching ratio. Therefor we simply assume 50% of all b-quarks decay into K^{+-} anything, and subsequently decay with muons. These K mesons and muons are probably much less energetic than those from s-bar jets, because they are going through b -> c -> s chain. If we assume the average energy of K mesons is 10 GeV, their probability of decaying within 0.5 m is 0.7 %, and the energy of the resulting muons may be about 5 GeV. The overall probability will 0.7 % with a factor of 2 for 2 b-quarks and 50 % decay into K mesons.

3. K from c-quark of W decay

The c-quark from a W hadronizes into D mesons and their excited states. We assume their energy is about 53 GeV, and a half of the D mesons decays into muons through K mesons. If we assume the energy of the K mesons is 18 GeV, then the energy of the muons maybe about 7 GeV on the average, high enough to be detected. But its decay probability within 50 cm is 0.5 % and with other factors or 0.5 x 0.5 the overall probability will be 0.1 %.

We need detailed Monte Carlo calculations for the estimation of K mesons effect, but it looks the combined effect for a top channel may be in the order of 1 % for the total number of the candidates with and without tagging. Also the tagging by the muons from π mesons may be in the same order of magnitude or less.

IX. Conclusions

When we are doing mass analysis on the lepton-jets and all-jets events, we should not assume the soft lepton tagging is automatically coming from a b-jet. There is a fairly large chance, about 15 % for lepton-jets channel and about 26 % for all-jets channel, that tagging is due to the c-quark of one of jets from the W decay. The probabilities of these tagging for the lepton-jets and all-jets channels are summarized in Table I. These probabilities will be affected with the detection efficiencies, and the selection cuts used for event selections. We need a further detailed Monte Carlo calculation for both top channels, to estimate accurate decay rates into tagging.

The energies of the b- and c-quarks are calculated with the top quarks at rest. The starting energies of the c-quark and b-quark are 53 and 69 GeV. And the starting energy of the cascade process is 23 GeV. Their energy values may go up in the real condition, or may be degraded by the fragmentation process. In the Monte Carlo calculation we should find out how the fragmentation into the excited states of the decay process will affect their energies.

This consideration of c-quark tagging will also affect the cross section for a top quark.

From the Table I, where the detection efficiency for tagging is not considered, we can expect 50 to 60 % of the lepton-jets and all-jets channels are soft muon tagged, and similarly tagged with electrons and taus.

In both lepton-jets and all-jets channels, there is possibility that decaying of a b-jet alone could produce a missing Et of about 20 GeV. And the energy correction for the top mass analysis is substantial.

Acknowledgments

We gratefully acknowledge the critical and useful discussions and suggestions from the following persons, Drs. K. Bazizi, M. Jones, N. Oshima, T. Ohnogi, H. Xu, T. Yamanouchi, D. R. Wood.

References

1) H.B. Greenlee, ' Search for Top Quark in the Single Lepton + Jets Channel at D0 ', Proceeding of 9th Topical Workshop on Proton-Antiproton Collider Physics. 357 (1993).
2) F. Abe et al., Fermilab-Pub-94/116-E, submitted to Physical Review Letter.
3) Particle Data Summary : Physical Review D, 50, 1173 (1994).
4) K.A. Bazizi, ' Inclusive B Production at CDF and D0 '. Presented at XXIXth Rencontre de Moriond on QCD and High Energy Hadronic Interactions, 1994.

Appendix I Major Decay Modes for c-Jets with muons 3)

The c-quarks hadronize into D^{+-}, D^0 and D_s^{+-} mesons and their excited states. Their major decay modes with muons are,

D^+ decay modes (D^{+-} cdbar, dcbar m=1869.4, τ=1.06 x 10^{-12} s, $c\tau$=0.317mm)

Inclusive modes

e^+ anything	17.2 %	
μ^+ anything	?	(not listed)
K^- anything	24.2 %	
K^0bar anything + K^0 anything	59 %	
K^+ anything	5.8 %	

Leptonic and semileptonic modes

K^0bar $\mu^+ \nu_\mu$	**7.0 %**
$K^-\pi^+\mu^+\nu_\mu$	**3.2 %**
mostly from (K^*bar$(892)^0$ --> $K^-\pi^+$)	
$\phi\ \mu^+ \nu_\mu$	**< 3.7%**

D^0 decay modes (D^0 cubar, ucbar m=1864.6, τ=0.415 x 10^{-12} s, $c\tau$=0.124mm)

Inclusive modes

μ^+ anything	**10.0 %**

semileptonic mode

$K^-\ \mu^+ \nu_\mu$	3.2 %

D_s^+ decay modes (D_s^{+-} csbar, scbar m=1968.5, τ=0.47 x 10^{-12} s, $c\tau$=0.14 mm)

Inclusive modes

e^+ anything	< 20 %	
μ^+ anything	?	(not listed)
K^- anything	13 %	
K^0bar anything + K^0 anything	39 %	
K^+ anything	20 %	

Leptonic and semileptonic modes

$\phi l^+\nu_l$	**1.9 %**
$\eta\mu^+\nu_\mu$ + $\eta'(958)\mu^+\nu_\mu$	**7.4 %**

Appendix II Major Decay Modes for b-Jets with muons 3)

The b-quarks hadronize into B^{+-}, B^0 and their excited states.

B^{+-} decay mode (B^{+-} ubbar, bubar m=5278.7, τ=1.54 x 10^{-12} s, cτ=0.388mm)

Semileptonic and leptonic modes

B --> $\mu^+ \nu_\mu$ anything **10.3 %**

D, D* or D_s modes

B	--> D^- anything	26 %
	--> D^0bar anything	54%
	--> $D^*(2010)^-$ anything	23 %
	--> D_s^{+-} anything	8.9 %
	--> D_sD, D^*_sD, D_sD^*, $D^*_sD^*$	5.0 %

Charmonium modes

B	--> $J/\psi(1S)$ anything	1.3 %
	--> $\chi_{c1}(1P)$ anything	1.1 %

K or K* mode

B	--> K^{+-} anything	85 %
	--> K^0/K^0bar anything	63 %

Baryon mode

B	--> charmed-baryon anything	6. 4%

B^0 decay mode (dbbar, bdbar m=5279.0, τ=1.50 x 10^{-12} s, cτ=0.449 mm)

Semileptonic and leptonic modes

$l^+ \nu$ anything **9.5 %**

$D^- l^+ \nu_l$	1.9 %
$D^*(2010)^- l^+ \nu_l$	4.4 %

Appendix III Major decay modes of sbar-jets with muons 3)

The sbar quarks in (5), which are generated from the W decays hadronize into charged and neutral K mesons and their excited states. Their major decays with muons are as follows,

K^{+-} decay (usbar, subar m = 493.7, τ = 1.24 x 10^{-8} s, cτ = 3.7 m)

$\mu^+\nu_\mu$	**63.5 %**
$\pi^0\mu^+\nu_\mu$	**3.2 %**

K^0 decay (dsbar, sdbar m = 497.7)

K^0_S (τ = 0.89 x 10^{-10} s, cτ = 2.7 cm)

no decay with muon

K^0_L (τ = 5.2 x 10^{-8} s, cτ = 15.5 m)

$\pi^{+-} \mu^{-+} \nu$ **27.0 %**

Appendix IV Inclusive Muon Cross Section 4)

The cross section of inclusive muons, mostly for QCD events, in the energy range of Tevatron Collider experiment is reported, and its cross section is shown in Fig.1. 4) This does not correspond to the events, which we are looking for in this report. They are buried under the QCD events. Even though this may be misleading, we just estimate the ratio of decaying b-quarks and c-quarks from this curve for comparison. The decay probabilities of these quarks depend on their pt values. The data show that the ratios of (b -> μ + X) / (c -> μ + X) is about 1.3, 2.0, 2.5, 2.7 at pt = 5, 10, 15, and 20 GeV respectively. These data do not correspond to the case of W decays, but are suggestive of fair amount of contribution from c quarks relative to b quarks.

Fig.1 Inclusive muon cross section at root s = 1.8 TeV. From Ref. 4)